BIRD-AIRCRAFT STRIKE THREAT ASSESSMENT USING AVIAN RADAR INFORMATION

By:
Jinfeng Wang and Edwin E. Herricks
Center of Excellence for Airport Technology
Department of Civil and Environmental Engineering
University of Illinois
Urbana, IL 61801
USA
Phone: (217) 244-1109
Jwang56@illinois.edu

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INTRODUCTION

Bird-aircraft collisions or bird strikes have been a major concern to aviation safety since the early days of aviation. The number of bird strikes has increased sharply over recent years and is expected to keep increasing in the United States and perhaps throughout the world due to the increasing air traffic and bird population. More than 12,500 bird strikes occur every year to US civil and military aircraft, as reported in Richardson [1]. Richardson's financial evaluation shows that bird strikes cost the U.S. commercial aviation over $600 million every year.

Birds near the airport post serious threat to the aircraft. Statistical analyses in Transport Canada [2], Cleary et al. [3] and FAA [4] show that about 91% of departure collisions and 83% of arrival collisions occur within 5 nautical miles (9260 meters) of the airport and 92% of all bird strikes happen below 3000 feet (914.4 meters) relative to ground level. Because there is no effective way to influence bird activity in the air, the only chance to minimize the threat of bird strikes is to avoid flying through regions with high bird density. Therefore, evaluating bird strike threats to aircraft near the airport is a very critical element in programs to reduce bird strikes.

Bird strike threat is directly influenced by bird activity in terms of bird density (bird count/area), bird body mass, collision speed and flight direction as mentioned in Tedrow [5], Dolbeer [6] and Transport Canada [7]. Although the threat is generally assumed to be higher in areas where bird densities are high, the result may not be consistent with the assumption because of the area location (e.g. close to or far away from aircraft flight routes), bird species and bird flight behavior. Collision speed is important where more damage is likely at higher speeds, so collisions at higher altitude may be more damaging because speeds are greater.

It is more meaningful to evaluate bird strike threat in some critical target areas inside and outside the airport where bird strikes mostly occur. Radar has been proven to be a useful and effective tool in bird movement study since the 1960s in Eastwood [8] and Gauthreaux et al. [9]. With radar, information collected for a target can include velocity, heading direction, latitude, longitude and altitude. Radars function around the clock and operate effectively under poor hearing and viewing conditions. Advancement in radar and processing technology support analysis of bird movement dynamics.

In this study, we use radar to collect bird activity data to further evaluate bird strike threats to aircraft operations at the Naval Air Station Whidbey Island (NASWI), located in Oak Harbor, Washington. The overall wildlife management program at NASWI is designed to improve safety through bird hazard management. The NASWI installation has two sections: Ault Field, which is the focus of aircraft operations, and the Seaplane Base, which provides administration and housing support for NASWI staff. The threat analysis focuses on Ault field, located on the Strait of Juan de Fuca. The Strait of Juan de Fuca is a large water body connecting the Georgia Strait and Puget Sound to the Pacific Ocean. The geographical location of Ault Field is 48° 21' 8" N, 122° 39' 15" W. As shown in Figure 1, there are two runways that form an "X" pattern: runway7/25 is oriented east/west and runway 14/32 is oriented north west/southeast. There are also several taxiways connecting runways and the military aircraft ramp areas. The Strait attracts many seabirds, and there is a large bird community that includes raptors, passerines, and waterfowl in the area. Our objective was to evaluate bird strike threat in critical target areas on and around Ault Field using a threat assessment model.

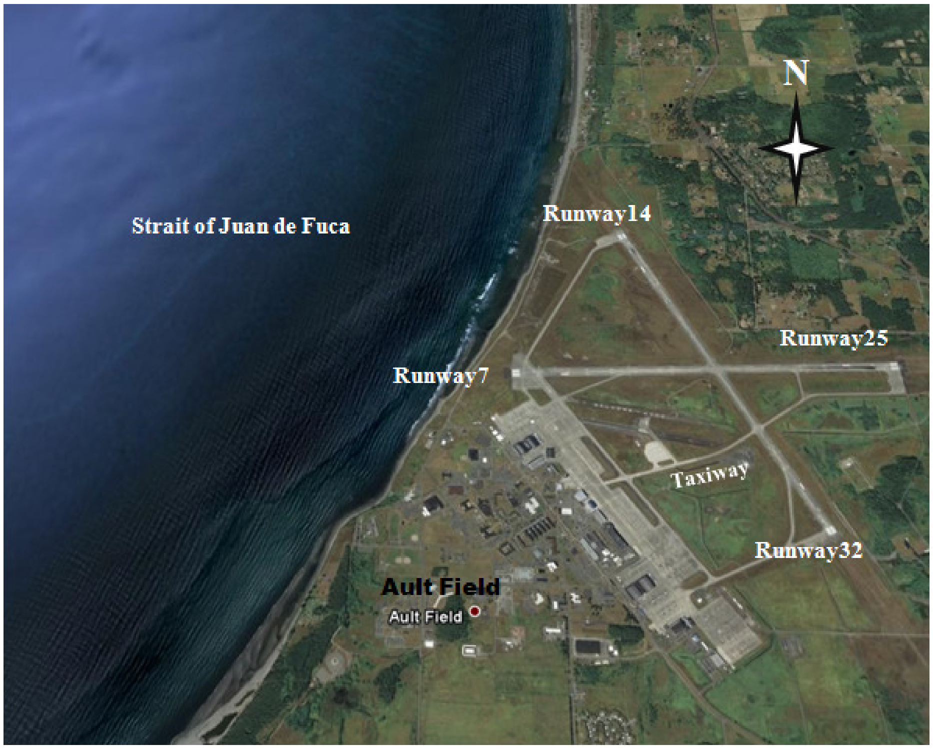

Figure 1. Research Area: NASWI Ault Field, WA (Source: Google Earth)

DATA AND METHODS

Data used for this study include bird activity data, wind data and GIS data that defines runways and taxiways on Ault Field. Bird activity data was collected using an Accipiter Avian Radar Technologies, Inc., 25 kW, X-band marine radar operating at 9.4 GHz with a wavelength of 3 cm. The radar sensor was equipped with a slotted array antenna providing a nominal 20 degree high by 2 degree wide beam. Data from the radar data processor provided detection time, track ID, ground speed, heading direction, latitude and longitude. The processor also assembled tracks from target plots. Data from 09/01/2008 to 09/28/2008 was used in the threat assessment. In addition to radar data, visual observations were made of local bird activity. Observations were made from 09/26/2008 to 09/28/2009 during which visual observation was correlated to radar detection. For each bird observation, we recorded time, bird species, heading direction and confirmed radar track ID. Wind data for a local weather observation station (KNUW) was provided by Department of Atmospheric Sciences at University of Washington. Wind speed and wind direction were recorded hourly. GIS data of runway and road regions are digitized from aero photos using GIS tools.

The threat assessment methodology includes two steps: (1) a data pre-processing, in which bird activity data (e.g. tracks of birds) are extracted and classified into bird groups; and (2) threat modeling, in which bird strike threat index value in each target area is determined.

The avian radar system is designed to detect bird targets, but the radar can also detect insects, vehicles, and aircraft and environmental conditions, such as rain or wind induced wave patterns on the Strait that may influence detection and tracking as mentioned in Eastwood [8]. To minimize the effects of non-bird tracks, we developed methods based on target movement patterns and track characteristics to extract bird tracks and eliminate non-bird tracks. Target tracks with airspeeds lower than 6m/s are assumed to be insect tracks. Aircraft and vehicle tracks were removed by assuming that a track is a vehicle or airplane if 80% of track points are within a road/runway region or the ground speed is over 50 m/s. Precipitation and wave action tracks were removed using Gaussian mixed cluster analysis.

Bird strike threat is directly affected by the kinetic energy created in the collision. So theoretically, it is a function of bird body mass, collision speed, flight direction and distance from the aircraft. Since it is very difficult to obtain exact body mass of each detected bird target, we proposed an “airspeed equivalent group” (AEG) to classify birds into groups based on their airspeed (Table 1). AEG is defined as a group of birds flying at similar airspeeds. Based on visual observation data, there is a dominant bird species in each AEG. We use the average body mass of the species in the same AEG when evaluating bird strike threat.

Table 1.
Airspeed Equivalent Group (AEG) and Its Dominant Bird Species.

AEG	Species	Mean Airspeed (m/s)	SD	Observed No.	Dominant Species
1	Foraging Red-tailed Hawk	6.183	3.094	8	Red-tailed Hawk
2	Gull	11.060	2.920	294	Gull
	Passerine	11.636	5.5546	23	
	American Crow	11.180	1.270	9	
	Herons	11.871	4.164	5	
3	Scoter	15.000	3.200	22	Scoter
	Cormorant	14.374	3.554	23	Cormorant
	Duck	14.487	4.923	11	
	Canada Geese	13.389	4.006	5	

Because aircraft are cooperative targets following known flight routes, we assumed that there is little threat if a bird is very far away from the aircraft or its flight routes (e.g. runway). So, we only considered birds with positions near aircraft routes or near critical target areas on the airport. These critical target areas have a higher potential for birdstrikes. The configuration of critical target areas is determined based on aircraft landing and takeoff information and flight-path altitude, as shown in Table 2. We use 305m (1000 ft) altitude as the beginning of a fixed angle approach or departure path.

Table 2.
Altitude and Aircraft Landing/Takeoff Angles.

Runway	Altitude (m)	Landing Angle[a]	Takeoff Angle[a]
7	305	2.44º	4.05º
14	305	2.88º	4.05º
25	305	3.38º	4.05º
32	305	2.61º	4.05º

[a] based on FAA Information for Airports [9]

In this analysis the focus was on the Strait end of the Ault Field runways, runways 7 and 14. As shown in Figure 2, target areas A and B are along runway 14, and target areas C and D are along runway 7.

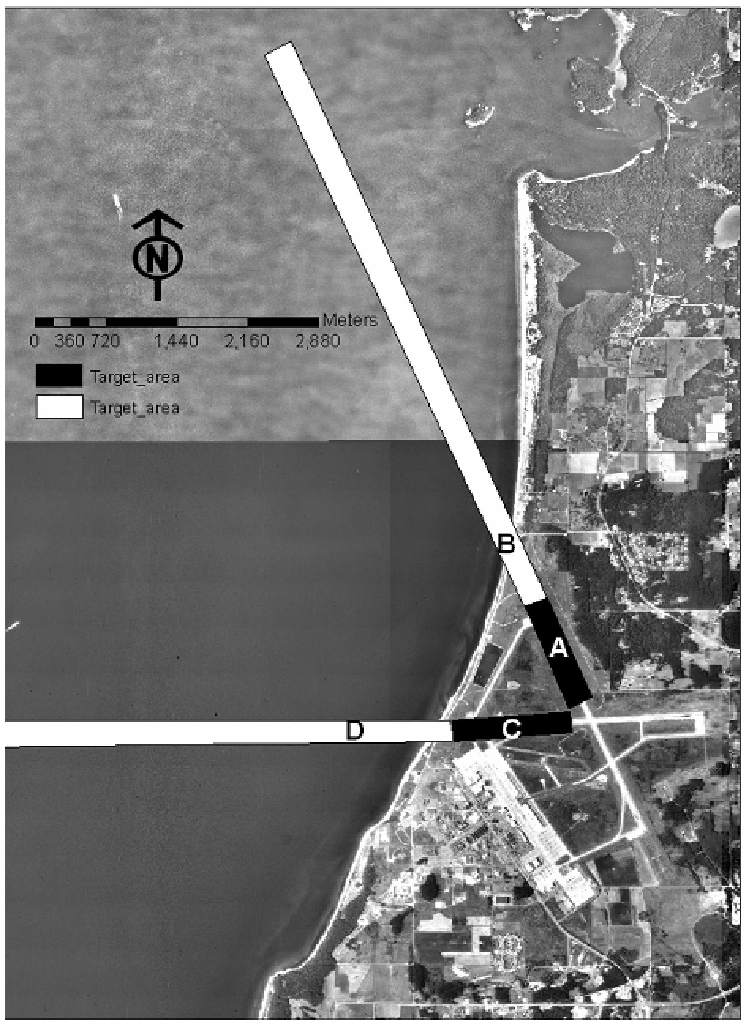

Figure 2. Locations of Target Areas.

More detailed information about the four target areas, including location, size (length and width), land cover type and aircraft flight phase, are summarized in Table 3.

Table 3.
Latitude and Longitude of Four Target Areas.

Target Area	Runway	Location		Size		Land Cover	Flight Phase
		Latitude	Longitude	Length (m)	Width (m)		
A	7	48.352966 48.361872	-122.65640 -122.66255	1057	261	Concrete Road, Grass	Landrolling Taking Off
B	7	48.361872 48.398863	-122.66255 -122.68921	6345	261	Water	Approaching Climbing
C	14	48.351861 48.351275	-122.65725 -122.67296	1121	261	Concrete Road, Grass	Landrolling Taking Off
D	14	48.351275 48.348986	-122.67296 -122.73027	5047	261	Water	Approaching Climbing

As indicated in the following equations, bird strike threat in target area j is measured as threat density, which is defined as the summation of the bird strike threat caused by each bird within target area j divided by the area of target area j.

$$Threat\_density_j = \frac{\sum threat_{ij}}{area_j}$$

$$threat_{ij} = \frac{1}{2} bodymass_{ij} * collision\_speed_{ij}^2 * heading\_index_{ij} * dist\_index_{ij}$$

Subject to: $i = 1, 2, 3, \ldots, n$;

$j = 1, 2, 3, 4$;

Where $Threat\_density_j$ is threat density index of target area j; $threat_{ij}$ is bird strike threat caused by a individual bird; $area_j$ is the area of target area j; $bodymass_{ij}$ is the body mass of individual bird i in target area j; $collision\_speed_{ij}$ is the relative ground speed of individual bird i to the aircraft in target area j; $heading\_index_{ij}$ is the heading parameter defined for individual bird i in target area j; and $dist\_index_{ij}$ is the distance parameter defined for individual bird i in target area j.

Four parameters are used in the evaluation of threat caused by a individual bird: $bodymass_{ij}$, $collision\_speed_{ij}$, $dist\_index_{ij}$ and $heading\_index_{ij}$. As addressed previously, we use average body mass of the species in each AEG to represent body mass of each bird in that group. The mean body mass of each bird species and the mean body mass of AEG are summarized in Table 4. The value of $bodymass_{ij}$ is assigned after checking which AEG the bird target belongs to.

Table 4.
Bird Body Mass.

AEG	Species	Mean Body Mass[b] (kg)	Mean Body Mass of Dominant species(kg)	Mean Body Mass of the Group (kg)
1	Foraging Red-tailed Hawk	1.130	1.130	1.130
2	Gull	0.447	0.447	0.443
	Passerine	0.028		
	American Crow	0.400		
	Herons	2.220		
3	Scoter	1.161	1.593	1.498
	Cormorant	2.025		
	Duck	0.609		
	Canada Geese	2.513		

[b] based on information in The Birds of North America Online [10], Dunning [11], Bruderer and Boldt [12], and Spear and Ainley [13].

The $collision\_speed_{ij}$ was calculated by the ground speed of a bird target and that of the aircraft which can be obtained directly from the radar data.

Distance effect was assumed to follow a mixed distribution as shown in Figure 3. We assumed that the aircraft follows a path projected from the central line of the runway. Based on near miss analysis (Klope et al. [14]) we considered a bird strike occurs any time a bird enters within 50 m of an operational aircraft. The parameter value of $dist\_index_{ij}$ within this distance is set to be 1. It decreases with the increasing distance.

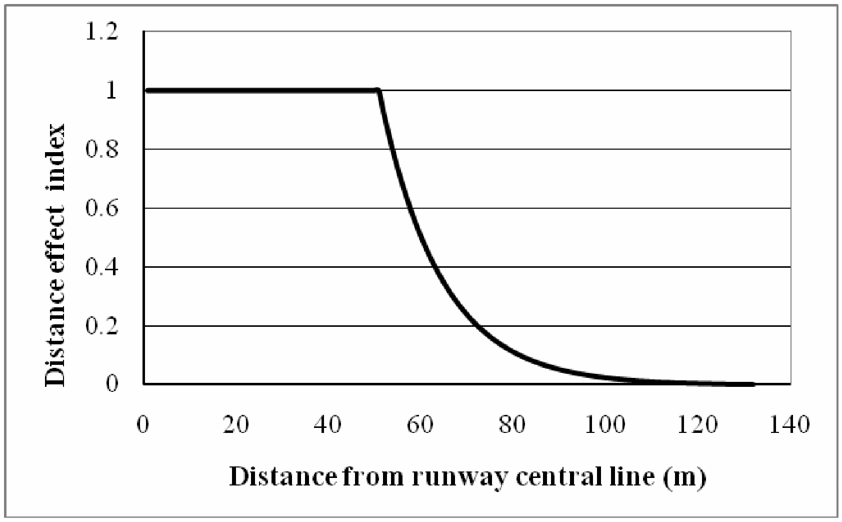

Figure 3. Distribution of the Distance Effect Index

Heading effects were classified into four categories based on bird heading direction and runway orientation as shown in Figure 4. The parameter value of each category is summarized in Table 5. The value of $heading\_index_{ij}$ is determined after checking which category the flight direction matches. There is an exception: if the $dist\_index_{ij}$ value of a bird target is 1, its heading effect index $heading\_index_{ij}$ will equal to the maxima value. It means that when birds are within 50 m of an operational aircraft, their heading effect indices equal to the maxima value no matter what directions they are heading to.

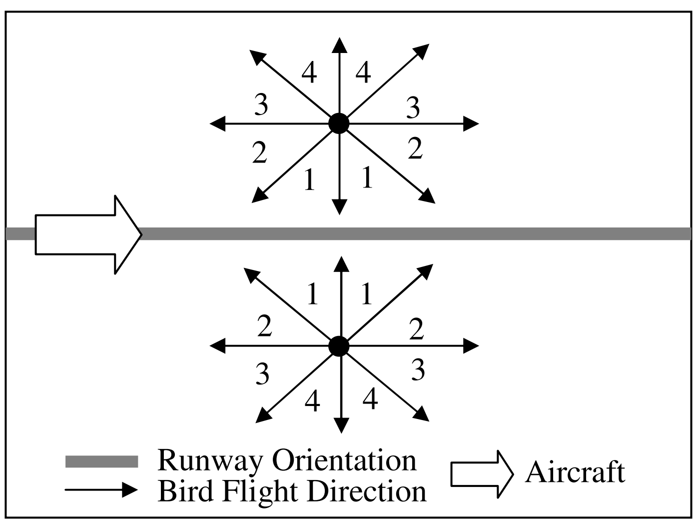

Figure 4. Categories of Bird Heading Direction

Table 5.
Parameter Value of Heading Index

Category	Heading Effect	Parameter Value
1	Very high	10.0
2	High	7.0
3	Low	4.0
4	Very Low	1.0

RESULTS AND DISCUSSION

Continuous radar data from 09/01/2008 to 09/27/2008 was analyzed. The hourly activity results indicated that bird activity and averaged threat density varied at dawn and dusk. These changes may be caused by the switch between nocturnal and diurnal birds. Bird activity and averaged threat density also varied spatially, revealing two different trends that may be a function of land cover types:

- In target areas A and C, bird activity and averaged threat density started to decrease between about 6:00am and 8:00am and kept a relative low value until 7:00pm. This may be because target areas A and C include the runway area, which is used frequently during the daytime for aircraft landing and takeoff. Aircraft and avian safety management techniques repeatedly scare birds from these areas during daylight hours, so birds may have learned not to linger in these areas.

- In target areas B and D, bird activity and averaged threat density began to increase at 7:00am and remained at a relatively high value before 8:00pm. This may be because target areas B and D are mostly covered by water, which is considered an important attractant to birds. Because most seabirds are diurnal, the results showed a high value at daytime in both areas. Fewer birds were detected in target areas A and C during the daytime.

Results also showed that the changing pattern of both bird activity and threat density in four target areas in a 24 hour period were similar. However, daily variation may be influenced by factors other than bird activity at daytime and at night, like weather and wave action. Other small daily variations may be due to changes in temperature, wind direction and wind speed, which need to be further evaluated.

What does this mean for managers? Knowing the "what, where and when" of bird-aircraft strikes is important for wildlife management. Evaluations based on the collected data may help managers evaluate bird strike threat at their airports and support airport safety management goals.

For example, Figure 5 shows three bird groups (AEG_1, AEG_2 and AEG_3) in four target areas (Target areas A, B, C and D):

- Birds of AEG_1, primarily Red-tailed hawk, prefer target areas A and C.
- Birds from AEG_2, which is dominated by gull, take over 50% in target areas B and D.
- Birds in AEG_3, which is dominated by both Scoter and Cormorant, are distributed almost evenly in target areas A, B and D, but less in target area C.

By referencing the hourly bird activity, we can conclude that during the daytime, gull is the bird species that should be a first priority for management in target areas B and D. Historical data also shows gull as the most frequent bird species involved in bird-aircraft strikes in Ault Field. Based on AEG percentages revealed in target areas A and C, managers' attention should focus on controlling Red-tailed hawk and gull.

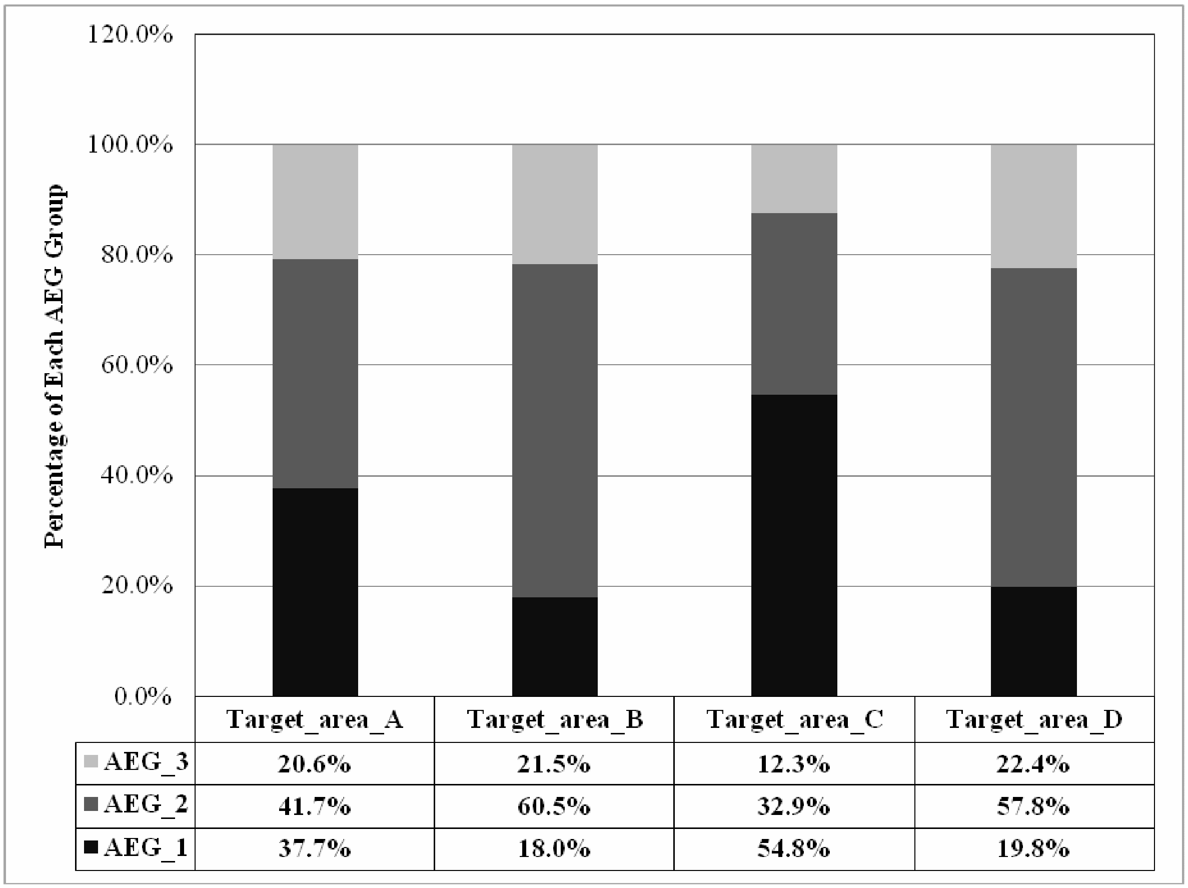

Figure 5. Ratio of Birds from Three AEG in Four Target Areas.

CONCLUSION

The model developed for bird strike threat assessment incorporates parameters of bird number (bird density), bird body mass, flight speed, flight direction, and the distance from the central line of the runway. Bird flocks and flight altitude are not included in this model because of the lack of data. The success of the technique relies on good data sets (visual bird observation data and radar detection data) and parameter determination. Parameters need to be re-evaluated before they are applied to other airports.

The evaluation results provide temporal and spatial variations of both bird activity and bird strike threat density in Ault Field, NASWI. The hourly analysis shows variations at dawn and dusk. The daily assessment indicates that daily bird activity and averaged threat density tend to be stable. Analysis of the collected data for daytime hours reveals that target areas B and D, which are covered by water, attract more birds than target areas A and C, which are mostly runway area. Bird species in target areas B and D are primarily seabirds. Bird species in target areas A and C are dominated by Red-tailed hawk and gull. Information such as this, based on the model's predictions, can aid in the assessment of bird strike threat and help direct wildlife management decisions.

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REFERENCES

1. Richardson, John W., and West, Timothy, "Serious Birdstrike Accidents to Canadian and U.S. Military Aircraft, 1928-2008: Numbers and Circumstances," Lecture, Bird Strike North American Conference, Victoria, British Columbia. Sep 15, 2009.
2. Transport Canada, "A Roadmap for the Development of a 3-D Airport Bird Detection Radar System for use at Commercial Airports in Canada," Detech Incorporated, Montreal, Canada, 2004.
3. Cleary, E. C., Dolbeer, R. A., and Wright, S. E., "Wildlife Strikes to Civil Aircraft in the United States 1990 – 2003," Federal Aviation Administration, Washington, D. C, 2004.
4. Federal Aviation Administration, Federal Aviation Administration National Wildlife Strikes Database Serial Report, Number 14, "Wildlife Strikes to Civil Aircraft in the United States 1990-2007," pp. 1-69, 2008.
5. Tedrow, C. A., *Bird Strike Risk Assessment for United States Air Force Airfields and Aircraft,* (Master's thesis), Virginia Polytechnic Institute and State University, Blacksburg, Virginia,1999.
6. Dolbeer, Richard A., Wright, Sandra E., and Cleary, Edward C., "Ranking the Hazard Level of Wildlife Species to Aviation," *Wildlife Society Bulletin* Vol. 28(2), pp.372-378, 2000.
7. Transport Canada, "Sharing the Skies Manual," http://www.tc.gc.ca/CivilAviation/AerodromeAirNav/Standards/WildlifeControl/tp13549/menu.htm, 2003.
8. Eastwood, E., *Radar Ornithology*, London, UK, Methuen, 1967.
9. FAA Information for Airports, at:
   http://www.airport-data.com/airport/NUW/
   http://www.fltplan.com/AirportInformation/NUW.htm

http://www.google.com/gwt/n?u=http%3A%2F%2Fwww.airnav.com%2Fairport%2FKNUW, 2009.

10. The Birds of North America Online, at: http://bna.birds.cornell.edu/bna/species
11. Dunning, Jr., J. B., *CRC Handbook of Avian Body Masses,* CRC Press, Boca Raton, FL, 1993.
12. Bruderer, Bruno and Boldt, Andreas, "Flight Characteristics Of Birds: I. Radar Measurements of Speeds," *IBIS*, Vol.143, pp.178-204, 2001.
13. Spear, Larry B.and Ainley, David G., "Flight Speed of Seabirds in Relation to Wind Speed and Direction," *IBIS*. Vol.139, pp. 234-252, 1997.
14. Klope, Matthew W., Beason, Robert C., Nohara, Timothy J., and Begier, Michael J., "Role of Near-Miss Bird Strikes in Assessing Hazards," *Human Wildlife Conflicts*, Vol. 3(2), pp. 208-215, 2009.